

## FEATURES OF CONTACT HEAT TRANSFER IN REACTOR FUEL ELEMENTS

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# FEATURES OF CONTACT HEAT TRANSFER IN REACTOR FUEL ELEMENTS

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In nuclear reactors good, uniform contact between the core and the jacket is highly important for the reliable performance of the fuel elements.

167

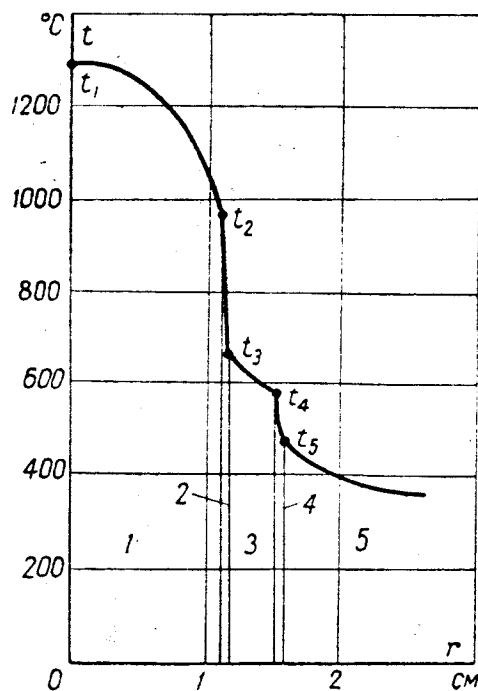
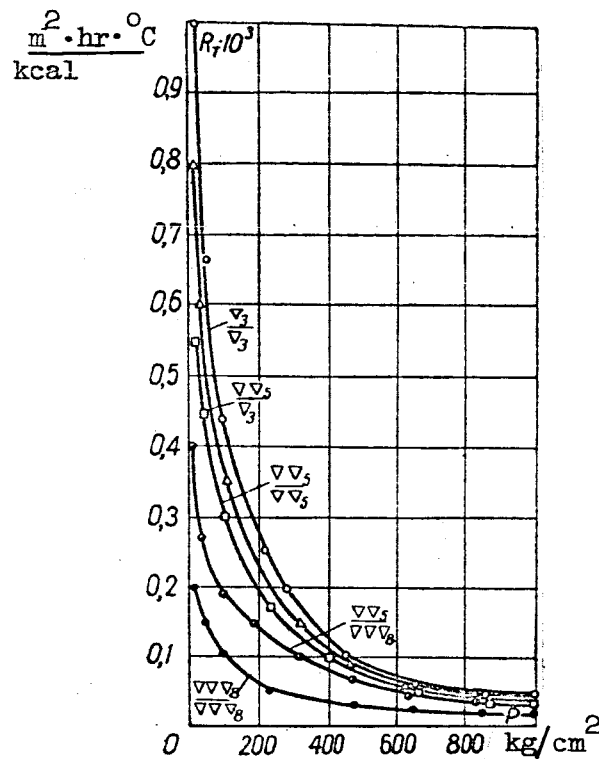


Fig. 1. Temperature distribution in a cylindrical fuel element.

$t_1$  - at center of fuel element;  $t_2$  - at core surface;  
 $t_3$  - at inside surface of jacket;  $t_4$  - at outside surface of jacket;  $t_5$  - temperature of heat-transfer medium.

1 - core; 2 - contact zone; 3 - jacket; 4 - boundary layer;  
5 - heat-transfer medium.



[commas represent decimal points]

Fig. 2. Thermal resistance as a function of the compressive stress and surface smoothness for the contact pair  $\text{ElKh13} - \text{ElKh13}$  steel under normal atmospheric conditions:

$$\Delta_3 - H_{av} = 58 \mu;$$

$$\Delta\Delta_5 - H_{av} = 11 \mu;$$

$$\Delta\Delta\Delta_8 - H_{av} = 3.1 \mu;$$

$$\lambda = \text{kcal/m} \cdot \text{hr} \cdot ^\circ\text{C}; \text{ hardness } H_B = 219.3 \text{ kg/mm}^2$$

If contact is poor, large thermal resistances may develop at the site of contact. These resistances may in fact account for a large part of the total resistance of the heat-transfer system. This involves a rise in the core temperature and, if the uniformity of contact is disturbed, temperature irregularities leading to warpage may appear in the core.

A typical temperature distribution in a cylindrical fuel element is shown in Fig. 1.

A preliminary calculation of the temperature drop at the surface between the core and jacket of the fuel element is not possible in view of the lack of basic data on the nature of contact thermal resistance and its dependence on various factors.

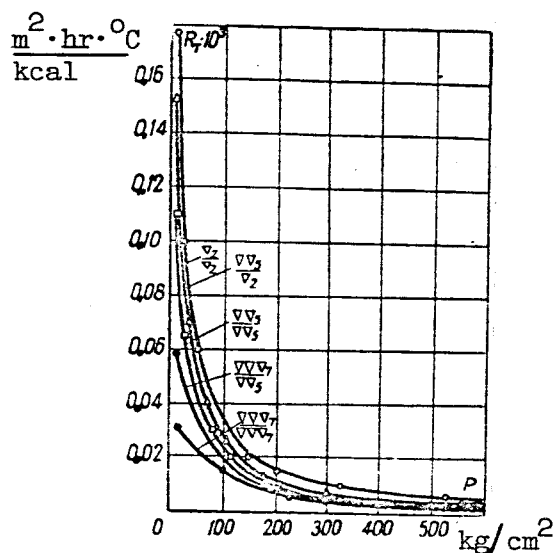


Fig. 3. Thermal resistance as a function of the compressive stress and surface smoothness for the contact pair aluminum-aluminum under normal conditions:

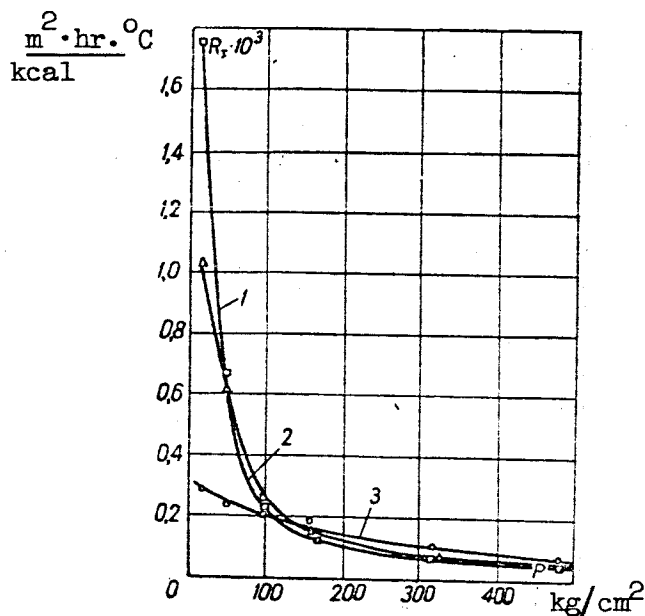
$$\Delta_2 - H_{av} = 65.7 \mu;$$

$$\Delta_5 - H_{av} = 11.8 \mu;$$

$$\Delta_7 - H_{av} = 4 \mu$$

$$\lambda = 175 \text{ kcal/m} \cdot \text{hr} \cdot ^\circ\text{C}; \quad \text{hardness } H_B = 75 \text{ kg/mm}^2$$

The author's experimental investigations of contact heat transfer between metallic and metal-ceramic surfaces have enabled him to derive the basic laws of the variation in contact thermal resistance as a function of different factors [4, 5].



[commas represent decimal points]

Fig. 4. Thermal resistance as a function of mean contact temperature and the compressive stress for the contact pair EIKh13-EIKh13 steel under normal atmospheric conditions:

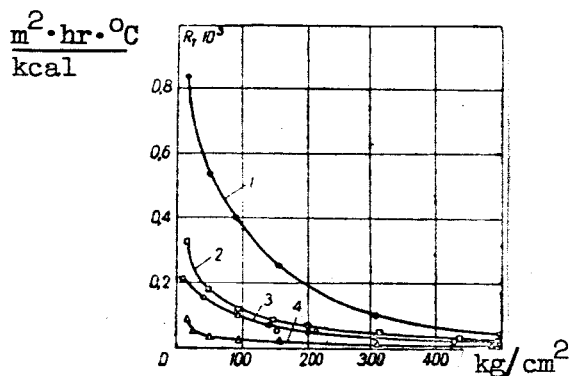
1 -  $t_K = 93^\circ\text{C}$ ,  $q = 32\,000\text{ kcal/m}^2\cdot\text{hr}$ ; 2 -  $t_K = 150^\circ\text{C}$ ,  
 $q = 56\,000\text{ kcal/m}^2\cdot\text{hr}$ ; 3 -  $t_K = 268^\circ\text{C}$ ,  $q = 107\,000$   
 $\text{kcal/m}^2\cdot\text{hr}$ ;  $\Delta_3 - H_{av} = 58\text{ }\mu$ ;  $\lambda = 22.5\text{ kcal/m}^2\cdot\text{hr}\cdot^\circ\text{C}$ ;  
 Hardness  $H_B = 219.3\text{ kg/mm}^2$ .

It was established that the process of contact heat transfer between the core and jacket of a fuel element depends on such factors as the compression, the physical nature of the contact, the properties of the medium present in the micro gaps, the mean temperature of the interface, and the effect of radiation on the properties of the contact materials.

The contact heat transfer was investigated at comparatively large specific heat fluxes ( $450,000$ - $500,000\text{ kcal/m}^2\cdot\text{hr}$ ) and high temperatures between the contact surfaces ( $350$ - $400^\circ\text{C}$ ) in the presence of different gaseous media, which corresponds to the conditions of heat

transfer between the core and the jacket of a fuel element.

From the derived laws of variation of thermal resistance in contact heat transfer we may draw certain fundamental conclusions, which should be taken into account in designing and operating fuel elements.



[commas represent decimal points]

Fig. 5. Contact thermal resistance of the pair of steels EIKh13-EIKh13 as a function of the heat conductivity of the medium and the compressive stress

1 - vacuum; 2 -  $\text{CO}_2$ ; 3 - Air; 4 -  $\text{N}_2$ ;  $\Delta\Delta\Delta$  -  $H_{av} = 3.1 \mu$ ;

a - Carbon dioxide,  $\lambda_{100^\circ\text{C}} = 0.019 \text{ kcal/m}^2\cdot\text{hr}\cdot^\circ\text{C}$ ; b - air,

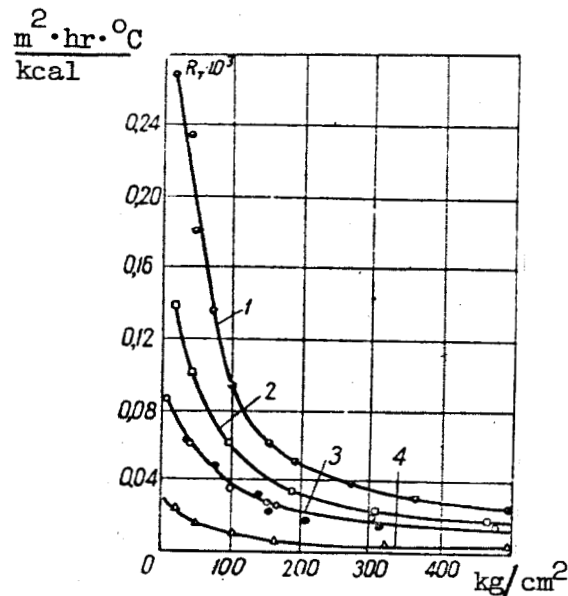
$\lambda_{100^\circ\text{C}} = 0.0276 \text{ kcal/m}^2\cdot\text{hr}\cdot^\circ\text{C}$ ; c - hydrogen,  $\lambda_{100^\circ\text{C}} = 0.189$

$\text{kcal/m}^2\cdot\text{hr}\cdot^\circ\text{C}$ ; d - vacuum,  $p = 10^{-3} \text{ mm Hg}$ .

{ It was experimentally established that an increase in the smoothness of the contact surfaces contributes to a decrease in thermal resistance. } This is because as the micro-roughness of the surfaces decreases there is an increase in the area of actual contact, and the conditions of heat transfer in the contact zone improve. However, this effect is not very significant in the case of soft metals (magnox, aluminum, etc.) under high-temperature conditions.)

[When the compressive forces are low and only isolated rough patches on the surfaces come in contact, other things being equal, the thermal resistance is considerable. With increasing compression, the thermal resistance decreases steeply and at high pressures becomes asymptotic (Figs. 2, 3).]

The compressive forces acting at the points of contact between the core and jacket of the fuel element are due both to precompression and to the pressure difference between the reactor heat-transfer medium and the gas filling the jacket.



[commas represent decimal points]

Fig. 6. Contact thermal resistance of the pair of steels 45-45 as a function of the heat conductivity of the medium and the compressive stress.

$$\Delta T_8 - H_{av} = 3 \mu.$$

The thermal resistance of the contact depends on the mean contact temperature of the core and jacket (Fig. 4). The decrease in this resistance with increasing mean temperature of the contact zone is due to the increase in the number of points of contact which, in turn, is due to the decrease in the hardness of the jacket.

The heat flux across the zone of contact mainly follows three paths: conduction through metal contacts and the intermediate gas layer and radiation between the surfaces.

If the heat conductivity of the materials in contact increases, the heat flux passing across the metal contacts will increase, and this will lead to a reduction in thermal resistance in the contact zone.

Experiments performed on contact pairs (EIKh13-45 steels, bronze, aluminum, copper) with a broad range of heat conductivities ( $\lambda = 22-321 \text{ kcal/m}\cdot\text{hr}\cdot^\circ\text{C}$ ) definitely confirm this assumption.

The actual area of contact between the surfaces accounts for an insignificant part of the geometric area of contact (1-2%) and increases with increasing pressure. The thermophysical properties of the gas layer located in the micro-roughnesses of the surfaces in contact considerably affect the magnitude of the contact thermal resistance.

An analysis of the experimental data establishes that most of the heat flux from the hotter to the cooler surface is due to conduction through the gaseous medium.)

In the investigations values of the thermal resistance were determined in gaseous media (air, carbon dioxide, hydrogen) with different heat conductivities ( $\lambda = 0.019-0.189 \text{ kcal/m}\cdot\text{hr}\cdot^\circ\text{C}$ ). It was experimentally demonstrated that as the heat conductivity of a gas decreases the contact thermal resistance considerably increases (Figs. 5, 6). If the contact planes are under vacuum conditions (the vacuum was maintained at  $p = 10^{-3} \text{ mm Hg}$ ), there is a sharp increase in the contact thermal resistance. /70

The presence of an oxide film at the surface results in a marked increase in the temperature drop in the contact zone. To reduce the thermal resistance any significant oxidation of contact surfaces should be avoided by employing special fuel element fabrication techniques.

During the production of fuel elements, good thermal contact between the core and jacket by diffusion bonding and various drawing techniques, and the space between the core and jacket is filled with a good heat conductor. All these methods, however, must be adapted to the specific operating characteristics of the fuel element, the permissible maximum jacket temperature, the neutron absorption, etc.

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